Rapid Hydrographic, Optical and Microstructure Surveys on the Continental Shelf and Slope

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LONG-TERM GOALS

To understand the dynamics of mesoscale circulation over the continental shelf and slope, with an emphasis on fronts, jets, eddies and topographic influences. To examine the relationship between circulation processes and the spatial distributions of mixing and optical properties over the continental margin.

OBJECTIVES

To investigate the relationship between mesoscale circulation and spatial distributions of mixing and optical properties over the continental shelf and slope. To understand how lateral variations in the density, velocity, mixing and optical fields influence variations in vertical mixing processes observed at a mid-shelf location. Specific objectives of this project are: to determine the characteristics and spatial scales of mixing and optical properties on the continental shelf and slope in the Middle Atlantic Bight south of Cape Cod; to investigate how distributions of mixing and optical properties depend on characteristics of the mesoscale coastal circulation; to describe how the characteristics and distributions of mixing and optical properties on the shelf differ between seasons and relate these differences to seasonal contrasts in coastal circulation and water-column structure.

APPROACH

As part of the Coastal Mixing and Optics (CMO) Accelerated Research Initiative, we made contemporaneous measurements of density, light absorption/attenuation and microstructure using sensors mounted on SeaSoar, a towed undulating measurement platform. The SeaSoar sensor suite includes a dual-sensor Sea-Bird CTD, a nine-wavelength spectral absorption and attenuation meter (WET Labs ac-9) and a new microstructure instrument (MicroSoar). Horizontal velocity is measured using a 300-kHz shipborne acoustic Doppler current profiler (ADCP). We conducted rapid surveys using R/V Endeavor during two 21-day field experiments in the Middle Atlantic Bight centered near

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40.5N, 70.5W, south of Cape Cod. We completed a summer survey, when the shelf is stratified, from 14-Aug to 1-Sep 1996 and a spring survey, when the shelf water tends to be more mixed, from 25-Apr to 15-May 1997. During each field experiment we collected data from repeated large-region surveys over a roughly 70 x 80 km box completed in about 2 days. Alternating with the large-region surveys, measurements were concentrated in a small box (roughly 25 x 25 km completed in 14 hours) centered around a mid-shelf location where the physical and optical fields were intensively sampled by our CMO colleagues using moored instrumentation and vertical profiling from a stationary ship.

The co-PIs on this project are J. Barth and P. M. Kosro. Two Faculty Research Assistants, R. O'Malley and J. Fleischbein, are responsible for CTD data processing and data report production. A Postdoctoral Research Associate, D. Bogucki, is working approximately one-quarter time with J. Barth to process and analyze the extensive optical data set. J. Simeon joined the group in Fall 1998 to pursue an interdisciplinary masters degree in physical and optical oceanography. Another Research Associate, S. Pierce, processed and is analyzing the shipboard ADCP data set. T. Dillon is leading the effort to process and analyze the MicroSoar data, together with help from a Faculty Research Associate, A. Erofeev.

WORK COMPLETED

We processed data from the instruments aboard SeaSoar, which made approximately 34,900 vertical profiles of the water column over the continental shelf and slope during the CMO cruises, and from the shipboard ADCP. Hydrographic fields obtained from the CTD onboard SeaSoar were reported in O'Malley et al. (1998), an online version of of which can be found at http://diana.oce.orst.edu/cmoweb/csr/main.html. During this year, we continued to analyze our own extensive hydrographic, velocity and bio-optical data sets and to collaborate with other CMO PIs.

Velocity data from the ADCP was processed using bottom tracking, DGPS ship's navigation and high-quality ship's heading from the R/V Endeavor's TANS system, and was reported in Pierce et al. (1998), online at http://diana.oce.orst.edu/cmoweb/adcp/main.html. Velocity data from our two 21-day CMO cruises together with moored velocity data from Levine and Boyd (SAS PRIMER, Jul-Sep 1996), Pickart (Shelfbreak PRIMER, Dec 1995 to Feb 1997), and Beardsley and Gawarkiewicz (Shelfbreak PRIMER, Jul-Aug 1996) have been used to estimate barotropic tidal currents in the CMO region. An empirical method following Candela et al. (1992) was used with bilinear polynomial spatial functions for M2 and K1, and zero-order functions for S2, N2 and O1.

Analysis and evaluation of data from the new microstructure instrument (MicroSoar) flown aboard SeaSoar continues. Data from the fast-response capillary microconductivity probe sampling at 2 kHz, from co-located temperature and pressure sensors, and from a three-axis accelerometer have been processed. Details of the MicroSoar design have been published (May, 1997) and a paper describing the MicroSoar system and the techniques for obtaining fields of temperature variance dissipation rate (chi), Cox number and heat flux has been submitted (Dillon et al., 1999). Finally, the entire CMO MicroSoar data set, including vertical sections and horizontal maps of microstructure properties, has been reported in Erofeev et al. (1998), online at http://diana.oce.orst.edu/cmoweb/micro/main.html.

Processing of optical data from the nine-wavelength absorption and attenuation meter (WETLabs ac-9) flown aboard SeaSoar has required new processing techniques. As reported in Barth and Bogucki (1999), it is critical to calculate a time-dependent lag between when the optical properties were

measured and when the CTD sensors sampled the same water parcel so that the optical data can be corrected for known dependence on temperature (and to a lesser extent on salinity) (Pegau and Zaneveld, 1994). Vertical sections of selected optical properties from the CMO cruises are available online at http://diana.oce.orst.edu/cmoweb/ac9/main.html.

RESULTS

Maps of the time-dependent three-dimensional distributions of hydrographic, velocity and optical properties over the shelf and slope in the Middle Atlantic Bight south of Cape Cod show the importance of advection and mesoscale (with horizontal dimensions of the size of the Rossby radius) and sub-mesoscale structure on vertical distributions at a mid-shelf location. Examples include intrusions from offshore at both the bottom and near the surface of warm, salty and relatively clear slope water, mesoscale meanders reaching forward from the shelfbreak front and jet, and packets of internal solitary waves propagating shoreward with attendant significant displacement of the thermocline and deep chlorophyll maximum at the base of the pycnocline. The spring 1997 cruise captured the restratification of the water column and an anomalous shoreward extent of a warm, salty bottom boundary layer driven by eastward near-bottom flow likely associated with a backward-breaking unstable meander of the shelfbreak front and jet.

From the empirical tidal velocity model, the M2 component contains 75% of the tidal variance and K1 another 9%. The M2 semi-major axis varies from 0.02 m/s over the slope to 0.30 m/s at the northeast corner of the CMO region. Ellipses tend to be nearly circular, especially near the CMO central site (40.5N, 70.5W). Comparisons with historical estimates for the region (Moody et al., 1984) showed plus or minus 0.02 m/s rms difference in M2 overall. The barotropic tidal prediction is used to produce subtidal velocity fields from the measured shipboard ADCP velocities, revealing the details of the frontal jets and eddies over the shelf and slope. An investigation of the internal tide in this region using the empirical model technique is underway.

D. Bogucki is investigating particulate resuspension induced by Internal Solitary Waves (ISW) during the 1996 CMO experiment. The analysis is based on mooring, tripod and SeaSoar data. A number of striking resuspension events were associated with the passage of long internal waves (Figure 1). An Adverse Pressure Gradient (APG) was generated by the ISW such that the near-bottom current reversed its direction on the leading edge of the ISW and the reversal lasted for most of the wave. The APG in turn led to resuspension events. The observations show that ISW are more efficient in resuspending sediment when generating an APG than in the absence of an APG. Furthermore, a measurable increase of light absorption by particulates (Beam C), i.e. resuspension of bottom material, in the absence of an APG requires a near-bottom (10 meters above bottom) velocity of approximately 1 m/s while bottom velocities of a few tens of cm/s are sufficient in the presence of an APG. A paper on these results is in preparation.

Dillon et al. (1999) described the details of a new high-frequency turbulence measuring instrument, MicroSoar. With appropriate assumptions about the local T-S relation, measurements of microscale conductivity fluctuations can often be used to directly determine temperature dissipation rate, the Cox number and the scaler diathermal turbulent diffusivity. Compared with conventional quasi-free-fall tethered vertically profiling instruments, MicroSoar's major advantage lies in its ability to sample large fluid volumes and large geographic areas in a short time. A cross-shelf section in the Middle Atlantic Bight south of Cape Cod, Massachusetts, reveals springtime restratification of the surface layer over

cold shelf water bounded on the offshore side by the stratified shelfbreak front. The temperature variance dissipation rate indicates strong mixing at the base of the surface mixed layer and at the seasonal thermocline. A branch of the high dissipation rate in the thermocline deepens and connects with very high dissipation rates near the bottom. Cox numbers were large near the shelfbreak front and diffusivities were as large as 10^{-3} m^2 s^{-1}, two orders of magnitude larger than mid-ocean thermocline diffusivities.

J. Simeon (OSU Graduate Student), with the guidance of J. Barth and C. Roesler (UConn), is decomposing the multi-wavelength light absorption measurements made from SeaSoar into contributions from the major absorbing components of seawater (phytoplankton, colored dissolved organic material — CDOM — and colored particulate material). She is also calculating the decorrelation lengthscales of the inherent optical properties (IOPs) and relating them to those for the hydrographic properties. Results of the decomposition method show modeled CDOM absorption compare well with in situ CDOM absorption observations by a nearby stationary vertical profiler. Two-dimensional summer distributions of IOPs (440 nm wavelength) of inshore water masses are coherent with phytoplankton and CDOM distributions. A sharp delineation by the shelfbreak front separates the optically clearer offshore water masses. To bound the spatial scales for which optical tracers can be utilized, horizontal decorrelation lengthscales were quantified for the hydrographic and IOP parameters. Temperature, beam attenuation and component absorption at 440 nm have decorrelation lengthscales of 5 km, 5 km and 2 km, respectively. The decorrelation lengthscales demonstrate that IOPs are variable on lengthscales 0-3 km shorter than variations in the hydrographic parameters.

Ryan et al. (1999) investigated how meanders of the shelfbreak front in the Middle Atlantic Bight during April-May 1997 were associated with chlorophyll enhancement following a hydrographic (the surface outcrop of the front) and a topographic feature (the shelfbreak at the 100m isobath). Satellite observations from the Ocean Color and Temperature Sensor of chlorophyll enhancement along these features was combined with cross-shelf SeaSoar profiles of physical and optical properties. Along two meander troughs, shoaling of cold shelf water was observed. Shelf water shoaled more than 20 m along frontal isopycnals, and phytoplankton absorption maxima coincided directly with shoaled water. Thus local nutrient enrichment by along-isopycnal upwelling was suggested as the mechanism for chlorophyll enhancement at the shelfbreak.

IMPACT/APPLICATIONS

By combining the simultaneous measurement of hydrography, velocity, optical properties and fine-scale temperature variance from over the continental margin, we expect to make progress understanding the dynamics of the interactions between these fields. This will contribute to a greater predictive capability for specifying the distributions and their time-dependent behavior over the continental margin.

TRANSITIONS

The MicroSoar technology is being packaged for use by R. Zaneveld (OSU) and for D. Hebert (URI). The MODAPS+ data acquisition and power supply system is being used by other (T. Cowles, OSU; C. Roesler, UConn) and is available from WETLabs, Inc. Our SeaSoar and shipboard ADCP data sets are available for use by CMO colleagues. The Optical Oceanography group at OSU (Zaneveld, Pegau, Barnard) is using our surface SeaSoar optical data from spring 1997 to verify their algorithms for

obtaining absorption properties from satellite ocean color sensors and to investigate to what extent optical properties on the shelf can be treated as conservative tracers (Pegau et al., 1999).

RELATED PROJECTS

We are collaborating with CMO colleagues who are using moored instrumentation and vertical profiling from a stationary ship to address the ARI's goals. We are also working with scientists who participated in the ONR PRIMER "Synthetic Aperture Sonar" conducted near the CMO central site.

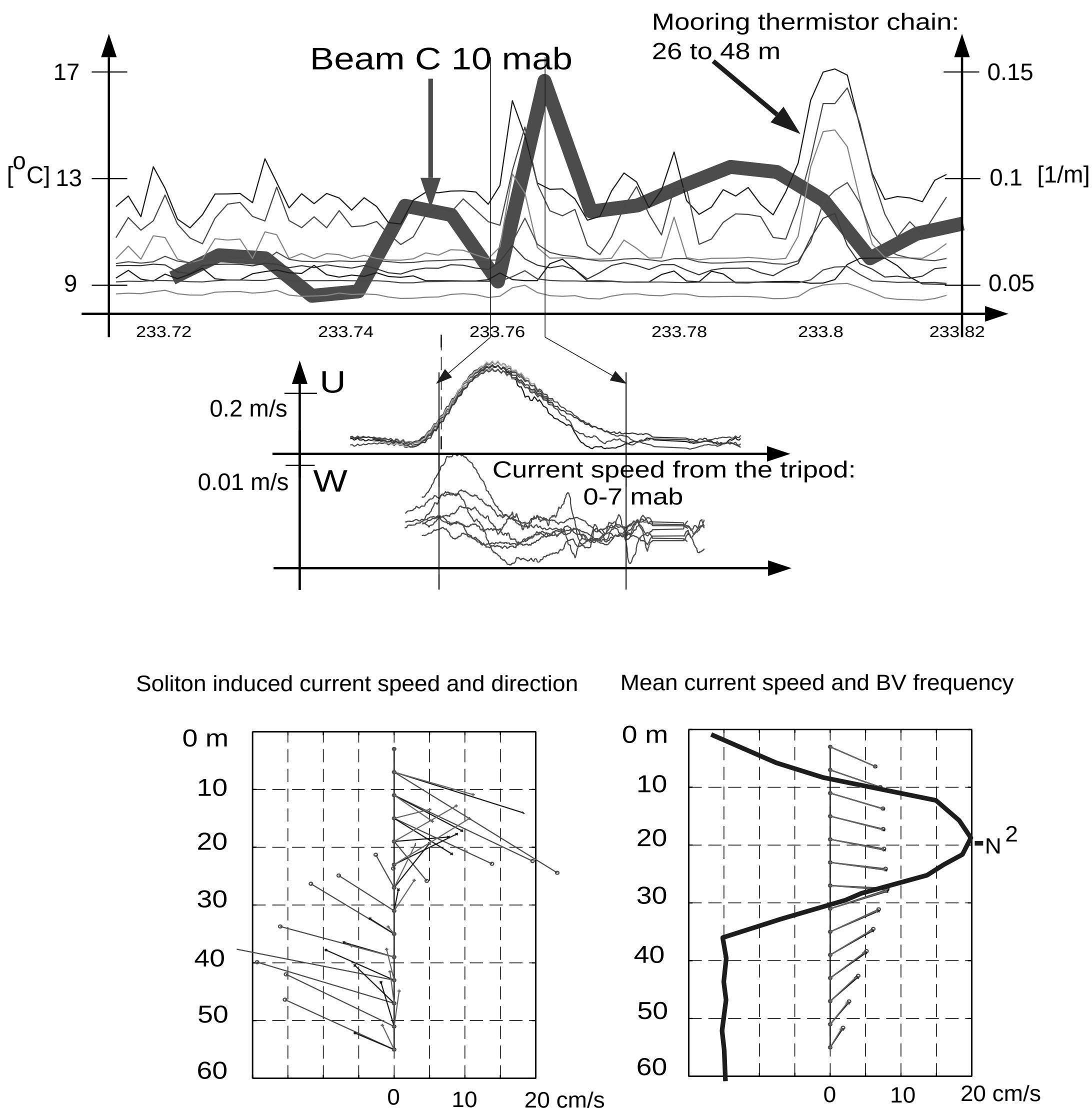

Figure 1. (top) Light attenuation (Beam C) at 10 meters above bottom (mab), and moored thermistor chain data from the CMO central site in 70 m of water on 20 August 1996. The increase of Beam C is associated with passage of an Internal Solitary Wave (ISW) of approximately 10-m amplitude. (middle) Near-bottom horizontal (u) and vertical (w) current speed recorded on the tripod. (bottom) Vector plot of ISW-induced (left) and mean (right) current speed and direction (E-W velocity is along the x axis and N-S velocity is along the y axis) and background BV frequency; several 1-minute averages are shown for the ISW-induced velocity. Data are courtesy of M. Levine, T. Dickey and J. Trowbridge.

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